(1950, 1951) in his C-twins. Albite and pericline laws (Gorai's A-twins) are also represented.

Biotite is the most important melanocratic constituent in these rocks. The black, lustrous, almost euhedral flakes are obvious in hand specimen. The dark mica is of the strongly pleochroic red-brown variety (γ = 1·643, X = very pale yellow-brown, Y = dark red-brown, Z = dark red-brown) and typically has haloes round certain small inclusions. Some of these appear to be zircon; others may be monazite. Rutile, iron-ore, and apatite are also included; the latter has not had much effect on the host (cf. Hutton, 1947). The biotite usually resists weathering processes but occasionally it is altered to muscovite and chlorite, excess TiO_2 being released as rutile to form sagenite webs (this alteration is probably more often related to late hydrothermal activity than to normal weathering). Bundles of sillimanite needles are common in biotite near strewn metasediment relics.

Muscovite is found as large blades and also sericitic aggregates. The larger muscovite flakes have 2V about 38° and β = 1·597. The aggregates are usually associated with myrmekite and altered felspar; they seem to be of late origin. Muscovite-quartz and biotite-quartz symplektites, associated with myrmekite, occur in certain metasediment inclusions as well as in the nearby granite itself. The association of the three types of intergrowth is always close and cases have been noted where the vermicular quartz of one passes, without interruption, into an adjacent intergrowth. Crushing is rarely observed near these features. Hills (1933) noted the association of myrmekite and biotite-quartz symplektite at Marysville (Victoria) and, following Väyrynen, suggested that it was related to the "crystalloblastic development of biotite from potash felspar, in which change plagioclase and quartz are liberated". This explanation is different from Sederholm's well-known hypothesis (see, for example, Drescher-Kaden, 1948; Seitsaari, 1951). Du Rietz (1938) attributed muscovite-quartz symplektites at Muruhatten (Sweden) to the "muscovitization" of microcline. Rest solutions attacked the microcline and the change to mica released SiO_2 to crystallize as quartz. The extensive development of sericitic mica from cordierite, sillimanite, and felspar in the high-grade metasediments of the country rocks (see Vallance, 1953*a*) may be related to the alteration to mica of felspar in the granites.

Apatite, zircon, rutile, iron-ore, tourmaline, and sillimanite may all occur as accessories in these rocks. A few grains of colourless andalusite have also been noticed (cf. the pink variety in the Cooma gneiss). Joplin (1942, p. 188) believes the colourless andalusite to be xenocrystal. Card (1895) recorded pieces of colourless to brown-red or blue andalusite, up to one pound weight, in Burra Creek, south of Tumbarumba. These may have come from a contaminated phase of the granite or pegmatite. Detrital monazite reported from Batlow and Tumbarumba (Card, 1920) may have been shed from the Green Hills granite. Curran (1896) mentioned topaz, garnet, and kyanite from Tumberumba [*sic*] as well as sapphire, ruby, and spinel (the last three are probably derived from the Tertiary basalts). Kyanite has not been found in any of the rocks of this district but apparently blue-grey tourmaline has been mistaken for this mineral (old slides in the Mining Museum, Sydney, labelled kyanite contain tourmaline). Curran's description of his "kyanite" does not tally with tourmaline, but his find has not been confirmed.

Chemical Data.

Six representatives of this group of rocks have been analysed—a granite, an adamellite, two granodiorites, a garnet-bearing aplitic rock, and a basic patch (inclusion) with the mineralogy of a quartz-mica diorite. These are all given in Table 2 together with comparable rocks from other parts of the great metamorphic belt and from Cooma. The granites from Oura, Cooma, and Albury all have SiO_2 in the range 70–73% and most of them have low lime contents. Where plagioclase becomes more important the lime content increases. The granodiorite from Willan's Hill, Wagga Wagga, is compared with the Woomargama gneiss (Joplin, 1947) near Albury. The Woomargama gneiss is believed to be related to the Albury gneiss, its higher lime content being regarded by Joplin as due to contamination by lime-bearing material. The specimen from the Corryong batholith (no. E) is chemically not unlike the Woomargama gneiss and the granodiorite from Willan's Hill. The garnet-bearing aplite is similar in composition to the oligoclase granites of Joplin (1947, Table 6). The biotite-rich patch (no. 5) represents a greatly altered sedimentary inclusion occurring in the granodiorite (no. 4); its composition will be discussed later (p. 204).

TABLE 2.

First-Group Plutonic Rocks and Similar Types.

	1	A	B	C	2	3	D	E	4	5	6	F
SiO_2 ..	72·53	71·93	70·65	70·44	71·33	66·98	66·43	67·67	67·74	54·86	75·53	76·10
Al_2O_3 ..	14·57	14·62	15·25	15·84	14·82	16·83	17·53	14·50	14·77	18·32	15·88	15·95
Fe_2O_3 ..	0·74	0·83	0·83	0·53	1·99	1·18	0·15	0·87	1·31	2·01	0·46	tr.
FeO ..	2·02	2·25	3·45	3·35	2·31	3·58	3·76	3·78	4·52	8·01	0·40	
MgO ..	1·04	1·18	1·63	1·24	0·99	1·84	1·91	2·21	1·62	4·16	0·29	0·11
CaO ..	0·70	0·91	0·94	0·73	1·60	2·88	2·55	2·18	1·58	1·95	0·65	0·23
Na_2O ..	2·25	1·98	1·77	1·70	2·61	2·12	2·37	2·38	1·97	2·46	2·80	2·90
K_2O ..	4·96	5·03	4·63	4·09	3·39	3·22	3·22	3·42	4·44	5·22	3·19	3·27
H_2O+ ..	0·72	0·75	0·60	0·62	0·89	0·80	0·61	1·81	0·89	1·30	1·01	} 1·16
H_2O- ..	0·11	0·34	0·09	0·09	0·12	0·14	0·21	0·11	0·26	0·22	0·09	
TiO_2 ..	0·42	0·33	0·65	0·66	0·52	0·67	1·10	0·61	0·70	1·18	abs.	—
P_2O_5 ..	0·09	0·22	0·12	0·22	tr.	—	0·07	tr.	—	—	0·15	—
MnO ..	0·04	0·03	0·05	tr.	0·04	0·05	—	tr.	0·05	0·14	0·04	—
Etc. ..	—	0·02	—	—	—	—	—	tr.	—	—	—	—
	100·19	100·42	100·66	99·51	100·61	100·29	99·91	99·54	99·85	99·83	100·49	99·72

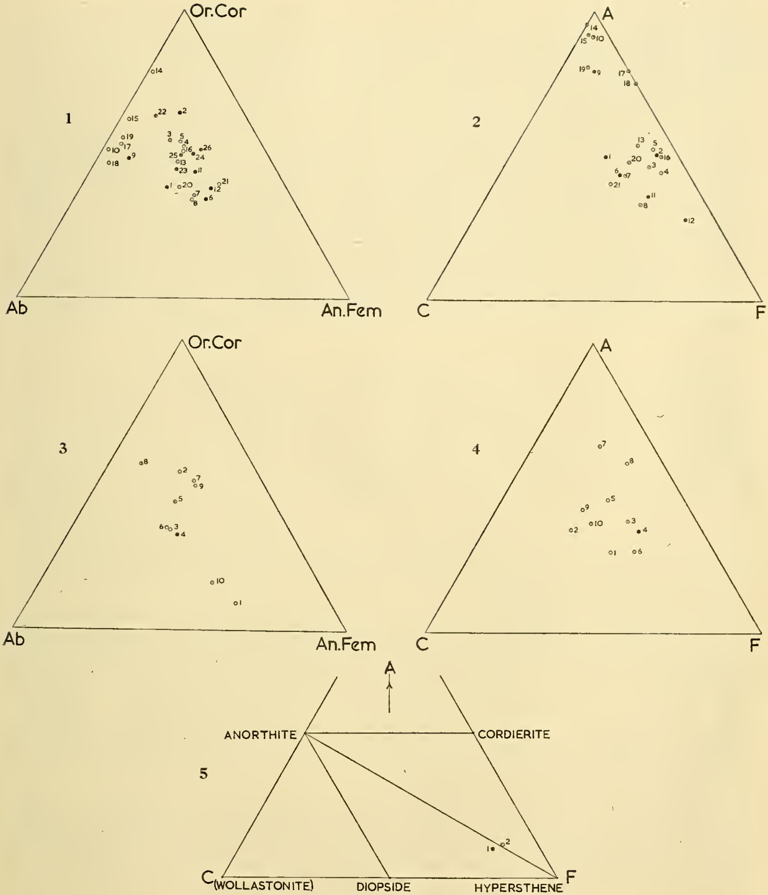
1. Biotite granite. Por. 235, Par. of Oura, Co. Clarendon. Anal. T. G. Vallance.
A. Granite. Mt. Wagra (Victoria). Anal. C. M. Tattam. *Bull. Geol. Surv. Vict.*, 52 : 38.
B. Cooma gneiss (with plagioclase phenocrysts). Cooma. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942 : 188.
C. Albury gneiss. Albury. Anal. G. A. Joplin. *Ibid.*, 72, 1947 : 117.
2. Biotite-adamellite. Creek bed, Por. 224, Par. of Oura, Co. Clarendon. Anal. T. G. Vallance.
3. Granodiorite. Quarry, north-east side of Willan's Hill, Wagga Wagga. Anal. T. G. Vallance.
D. Two-mica gneiss. Woomargama (Albury district). Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 72, 1947 : 118.
E. Grey biotite-granite. Par. of Cudgewa, Victoria. Corryong batholith. Anal. F. F. Field. *Proc. Roy. Soc. Vict.*, 50, 1937 : 82.
4. Granodiorite. Near Tenandra Trig. Station, Por. 218, Par. of Tenandra, Co. Clarendon. Anal. T. G. Vallance.
5. Biotite-rich patch in the granodiorite near Tenandra Trig. Station (no. 4). Anal. T. G. Vallance.
6. Garnet-bearing aplite. Por. 168, Parish of Bilda, Co. Clarendon. Anal. T. G. Vallance.
F. Muscovite granite. Omeo, Victoria. *Trans. Roy. Soc. Vict.*, 24, 1888 : 110.

On the Or.Cor:Ab:An.Fem diagram (Text-fig. 1) the plutonic rocks of the first group (Wantabadgery–Green Hills type) are somewhat widely spaced. They fall roughly into three classes, the acid phases (near the Or.Cor:Ab edge), the potash felspar-rich granites, and the more plagioclase-rich adamellites and granodiorites. Point no. 21 in this figure represents a hypothetical rock with two parts of granite with one part of a lime-bearing psammite (cf. Joplin, 1947, Tables 11 and 13). The rocks have also been plotted on an ACF diagram (Text-fig. 2) and, for comparison, the diagrams for the second-group plutonic rock and similar types have been placed below.

To summarize, the chief chemical features of these granitic rocks of the first group are the excess of potash over soda and the fairly general low lime content. Even when the CaO content is relatively high, most of it must be held in plagioclase because hornblende and other lime-bearing ferromagnesian minerals are absent.

Inclusions in the First-Group Granites.

Inclusions, ranging in size from tens of feet or more to a few inches across, are common in both the Wantabadgery and Green Hills masses. Most of the inclusions



Text-figures 1-5.

Text-figures 1, 2.—Point no. 1, This paper, Table 2, no. 2. 2, This paper, Table 2, no. 1. 3, This paper, Table 2, no. A. 4, This paper, Table 2, no. B. 5, This paper, Table 2, no. C. 6, This paper, Table 2, no. 3. 7, This paper, Table 2, no. D. 8, This paper, Table 2, no. E. 9, This paper, Table 2, no. 6. 10, This paper, Table 2, no. F. 11, This paper, Table 2, no. 4. 12, This paper, Table 2, no. 5. 13, Joplin, 1942, Table 8, no. II. 14, Joplin, 1942, Table 8, no. III. 15, Joplin, 1942, Table 8, no. IV. 16, Joplin, 1947, Table 12, no. III. 17, Joplin, 1947, Table 6, no. I. 18, Joplin, 1947, Table 6, no. II. 19, Joplin, 1947, Table 6, no. III. 20, Joplin, 1947, Table 11, no. III. 21, Two parts of rock (point 2) with one part of limy metasediment (Joplin, 1942, Table 4, no. II). 22, Vallance, 1953*a*, Table 1, no. 5. 23, Vallance, 1953*a*, Table 1, no. 6. 24, Vallance, 1953*a*, Table 6, no. 8. 25, Vallance, 1953*a*, Table 6, no. 9. 26, Joplin, 1942, Table 5, no. IV. The metasediments (nos. 22-26) indicate the close relationship between certain psammopelites and the granitic rocks.

Text-figures 3, 4.—Point no. 1, This paper, Table 5, no. A. 2, This paper, Table 5, no. B. 3, This paper, Table 5, no. C. 4, This paper, Table 5, no. 1. 5, This paper, Table 5, no. D. 6, This paper, Table 5, no. E. 7, This paper, Table 5, no. F. 8, This paper, Table 5, no. H. 9, Joplin, 1943, p. 171, no. V. 10, Tattam, 1929, Table III, no. 21.

Text-figure 5.—ACF diagram showing certain possible Pyroxene Hornfels Facies assemblages. Where silica is deficient spinel may appear as an extra phase. Point 1 (plotted without correction for spinel) corresponds to the analysis no. 1 in Table 3. Point 2 represents the Cooma ultrabasic rock (Table 3, no. A).

can be readily related to metasediment types occurring among the country rocks. In general, sillimanite is commoner in the inclusions in the Wantabadgery granite than in the metasediments around it. A fairly large mass of ultrabasic rock is included in the granite at Mundarlo. Quartz nodules are not uncommon as inclusions and may exhibit a tendency to have narrow marginal felspar-rich zones developed.

The great bulk of the inclusions belong to the series pelite-psammopelite-psammite. Alumina-rich rocks are characterized in this environment by the presence, often in abundance, of sillimanite. These inclusions do not appear to acquire a hornfels texture; in general, they resemble the high-grade zone rocks (Vallance, 1953*a*). The usual mineral assemblage in these inclusions is biotite, sillimanite, muscovite, quartz, and felspar, in varying proportions dependent upon the original composition. Tourmaline occurs in places. The felspar is often untwinned and may be intergrown with vermicular quartz. Complete equilibrium has rarely been attained in these rocks. A few inclusions, rich in muscovite and having patches of greenish biotite and chlorite, probably once contained cordierite. Dark biotitic selvedges are often seen around the metasediment inclusions.

Sillimanite occurs here as felted masses or, less frequently, as clear, colourless porphyroblasts (see Plate xii, B). Sometimes it is concentrated in quartz giving the well-known *faserkiesel*. Andalusite does not often appear in the inclusions. The characteristic mineral reaction in the pelitic inclusions is biotite $\rightarrow$ sillimanite (fibrolitization). As the first stage, sillimanite fibres and needles develop at the margins of the red-brown biotite and finally mats of sillimanite cover the whole flake. Even when the reaction has gone to completion it is sometimes possible to see the outlines of the original biotite. The displaced potash probably gives rise to K-felspar and perhaps, ultimately, muscovite. In some inclusions muscovite is also converted to sillimanite. At a later stage in the history of these inclusions the sillimanite becomes unstable and may be converted to micas.

The sillimanite development may be largely a metamorphic effect but perhaps volatile constituents related to the granite had some influence. Williams (1934) suggested that in Stewart Island (N.Z.) the formation of sillimanite in a sillimanite-tourmaline paragenesis was related to boron-bearing solutions. Tourmaline is associated with sillimanite in some of the inclusions here; occasionally, however, it appears to replace the sillimanite. It is interesting to note that recently Michel-Lévy (1950) has synthesized sillimanite from Al_2O_3 + SiO_2 mixtures with borax solutions at 400–450°C. and water vapour pressure of 50 kg/cm^2.

The exact amount of material added to these inclusions is difficult to assess, but that such action has taken place in many cases is indicated by the increase in felspar content near the margins of the inclusions and by the obvious quartzo-felspathic veins, sometimes arranged *lit-par-lit* fashion, in certain examples. As in the high-grade zone rocks, some of the felspar here may have been derived by purely metamorphic means but clearly a large part of it came from an external source. Increase in felspar content (both K-felspar and oligoclase occur in these metasomatized inclusions) usually is accompanied by a decrease in sillimanite; the latter often passes back to mica. Mechanical breakdown of the inclusions is assisted by the development of felspar porphyroblasts. The gradation from normal metasediment inclusion through felspathized inclusion to contaminated granite and granite is complete. Field evidence suggests that the psammopelite inclusions are more readily granitized than are the highly aluminous pelites. However, with increasing intensity of granitization it becomes more difficult to determine the original nature of the inclusions.

Only one metasediment inclusion has been analysed (Table 2, no. 5), but this gives us some interesting information. In hand specimen the rock has the appearance of a mica diorite but in the field it is obviously an inclusion and seems to be derived from a sediment. Its composition, however, shows that it has undergone considerable chemical re-organization. When plotted on a von Wolff diagram (Text-fig. 10, point no. 5) it can be seen that this rock is displaced, relative to the metasediments, away from the Q pole due to the abundance of L and M (as a result of the biotite present). Reynolds (1946) has shown that pelitic rock fragments in granite tend to become basified as part of a geochemical sequence leading to granitization. It is difficult to generalize from one analysis, but it seems evident that here the basic patch displays a marked excess of Fe, Mg, and Ti over that characteristic of either the metasediments or the granites. Reynolds suggests that in the conversion of pelites to granitic rocks two processes are important, basification, followed by granitization. Psammitic rocks may be converted to granitic material by granitization without much basification. Thus in the present case the rocks of sandy nature are readily made over into granitic types by the process of felspathization. With these changes in mind it is interesting to look back for a moment to the country rock metasediments. They, too, are plotted on Text-figure 10, but in them we do not see any clearly-defined geochemical culminations of the type noted above. Certain of the high-grade rocks are displaced away from Q relative to the lower-grade types but the displacement is not very great (cf. p. 214). There is no evidence of an important basic culmination (basic front) in the country rocks near the granite margins.

In addition to the numerous representatives of the aluminous pelite-psammopelite-psammite series discussed above, a few psammitic rocks with calcareous matrices occur as inclusions. Comparable types are not common among the country rocks. These inclusions are typically pale-coloured, often with green or yellow-green spots, and although traces of bedding or schistosity may be visible the rocks are often granulitic. The essential minerals of these limy inclusions are quartz and xenoblastic patches of clinozoisite-epidote. Green amphibole, garnet, felspar, iron-ore and, rarely, white mica may also be developed.

The clinozoisite-epidote has a dirty-brown colour and displays either normal epidote interference colours or anomalous blues. Amphibole may occur as ragged green porphyroblasts and is apparently actinolitic ($Z \wedge c = 20°$). Felspar is not abundant but both plagioclase (andesine-labradorite) and K-felspar have been noted in a few cases. Where felspar is developed, clinozoisite-epidote tends to disappear. Part, at last, of the Na and K required for the felspars must have been derived from the granite. Some of the inclusions carry ragged colourless garnets which, from their environment, are believed to be grossular-rich.

The metamorphic grade of these calcareous rocks does not seem to be as high as that indicated by the other metasediment inclusions. In Scotland, zoisite normally gives place to anorthitic plagioclase in the almandine zone but the reaction does not seem to have proceeded far here in rocks associated with others showing at least Amphibolite Facies assemblages. Epidote-quartz-actinolite-bearing inclusions in a granodiorite at Kozárovice (Hejtman, 1951) typically show marginal alteration to diopsidic pyroxene and hornblende in reaction rims. Such a scheme might be expected here but it has not been recognized.

An unusual mass of ultrabasic material, about 50 feet or more across, has been found in the Wantabadgery granite about half a mile east of Mundarlo homestead. In hand specimen the inclusion is a fine-grained, dark, dense granulitic rock. It consists essentially of amphibole, pyroxene, and green spinel, with a little talc, sphene, and iron-ore (see Plate xii, C).

The pyroxene is a hypersthene (colourless; –ve; apparent oblique extinction to 15°, but mostly straight) and occurs as ragged grains, not infrequently penetrated by amphibole blades. The amphibole is a pale, feebly pleochroic (X = colourless, Y = very pale yellow-brown, Z = pale yellow-brown; $\gamma = 1{\cdot}646$; $Z \wedge c$ up to 19°) variety occurring as aggregates of small blades or as individuals up to about 0·5 mm. long. Both positive and negative signs have been obtained (sections with two cleavages are often positive, with one they may be negative). Apart from differences in sign the amphiboles seem to be indistinguishable. The positive sign suggests that the mineral is cummingtonite, although γ is rather low (Simpson, 1932, has a cummingtonite with low refractive index; see also Winchell, 1951). The negative sign suggests a tremolite-actinolite which, from the paragenesis, must be a magnesian type. A fine flaky mineral (talc ?) occurs in patches. Small bright-green translucent grains of spinel are a common feature of these rocks.

The high magnesia content of this rock marks it as typically ultrabasic. No other ultrabasic rocks have been found in this area and as the only possibly related types are the silicified serpentines south of Nangus (Vallance, 1953*a*) the origin of this large inclusion is unknown. From what can be seen in the field the rock has been recrystallized without much reaction with the granite or much internal change in composition.

Rocks of similar chemical composition occur at Cooma (Joplin, 1942) as masses of chlorite amphibolite (see Table 3) within the zones of granitized schists. Ultrabasic types also occur as inclusions in the gneiss at Cooma; these are recorded as having what may be amphibole pseudomorphs after pyroxene. Mikkola and Sahama (1936) have described a metamorphosed ultrabasic rock (see Table 3) from Lapland consisting of rhombic pyroxene, amphibole (intermediate between hornblende and magnesia-rich tremolite-actinolite), green spinel, and a carbonate mineral.

TABLE 3.

	1	A	B
SiO_2	46·44	46·36	43·97
Al_2O_3	10·12	10·38	10·43
Fe_2O_3	3·98	5·68	1·47
FeO	8·30	3·24	7·14
MgO	21·32	24·69	23·44
CaO	6·54	5·08	6·84
Na_2O	0·78	0·46	0·30
K_2O	0·28	0·05	0·19
H_2O+	1·41	3·39	0·77
H_2O-	0·08	0·19	0·05
TiO_2	0·20	0·22	0·22
P_2O_5	—	0·03	0·09
MnO	0·12	0·42	0·20
CO_2	abs.	—	4·74
	99·57	100·19	99·85

1. Ultrabasic inclusion in the Wantabadgery granite. Por. 52, Par. of Mundarlo, Co. Wynyard. Anal. T. G. Vallance.

A. Chlorite-amphibolite. Pine Valley, Por. 70, Par. of Binjura. Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 67, 1942: 191.

B. Spinel-bearing pyroxene-amphibole-calcite rock. Kussuolinkivaara, Sodankylä (Finnish Lappland). Anal. L. Lokka. *Bull. Comm. Géol. Finlande*, no. 115, 1936: 366.

It seems clear from the rocks themselves that their present mineral assemblage is not in complete equilibrium. Hypersthene and spinel may be relics of the highest grade reached in the metamorphism. In the Pyroxene Hornfels Facies the rock should acquire a stable association of the type hypersthene-diopside-plagioclase-spinel. It will be seen from Text-figure 5 that diopside and plagioclase are not likely to be important here; neither has been definitely recognized. (In rocks of this composition similar mineral assemblages might be formed under either Pyroxene Hornfels or Granulite Facies conditions. The absence of garnet in the metasediments suggests the former here.) If hypersthene-spinel represents the metamorphic "peak", the assemblage shows some relation to that of Tilley's (1924) Class I Mg ii b hornfelses. Sedimentary hornfelses belonging to this class have been noted by Stewart (1946). The development of amphibole and talc may be related to a later retrogressive effect. These minerals are, in places, obviously derived from pyroxene and the reactions may be parallel to the late-stage conversion of the anhydrous high-grade mineral sillimanite to mica in some of the pelitic inclusions.

Dynamically-altered Granite.

Although signs of a fairly weak stress environment are not uncommon in the granite masses it is somewhat rare to find indications of intense dynamic action. Crush bands up to about 200 yards wide have, however, been found in the Oura–Wantabadgery district. They commonly trend about 15° east of north and may be traced for considerable distances in almost straight lines. Superficially they resemble long slate inclusions. The crushing is a wholly post-consolidation effect.

A complete gradation exists from normal granite to rocks with good cleavages (phyllonites—Knopf, 1931) or even to mylonites. Micaceous minerals in the granite yield to the stress by slipping and often develop intricate contortions across the cleavages. Biotite is converted to stretched-out patches of chlorite and sericite, often iron-stained. Any sillimanite present is converted to sericite. Quartz and felspar are more resistant and with intensification of the crushing may stand out as porphyroclasts. Usually, however, they develop cracks which lead to disruption of the grains. The felspar becomes sericitized whilst the quartz typically has undulose extinction. Narrow granular crush-bands may be set diagonally across the larger quartz grains and these lead to complete disintegration. Plate xii, D, shows the result of progressive crushing. Many of the rocks acquire an obvious slaty cleavage whilst a diagonal slip cleavage may also appear. The final product may have the assemblage sericite, finely-granular quartz, and some chlorite; this is a typical Greenschist Facies association. In some cases the frictional heat developed during the crushing bas been sufficient to weld together completely the crushed material. This is in marked contrast to the crumbly nature of the crush-rocks in the Ellerslie granite.

Granites of the Second Group.

The chief representative of this plutonic group forms the Ellerslie granite mass which occupies the floor of the open valley accommodating both Nacka Nacka and Yaven Creeks. Within the Parish of Ellerslie this granite is widespread. The mass has a somewhat irregular outline and comes into contact with a variety of rock types. As a rule the granite is more easily eroded than are the surrounding rocks. With a broad, rounded north-western end (near the locality known as Clearmont), the mass gradually tapers to the south-east, becoming quite narrow near Sharp's Creek village (west of Wondalga). It apparently persists, however, as far as Peel's Creek (west of Batlow) and Batlow. The maximum length is more than 20 miles and the width about 5 miles.

There is quite a variation in the appearance of the rocks of the Ellerslie mass. Often they are markedly gneissic biotite-bearing granites and granodiorites but more massive (usually still with traces of foliation) phases are not rare. The distribution of the two types is irregular and they have not been mapped separately.

Similar to the Ellerslie granite are the rocks outcropping along Adelong Creek north of Adelong and, to the south, near Wondalga. This mass is traversed by the Tumbarumba road from near Adelong to within three miles of Batlow, where it passes off into unmapped country to the east. It is proposed to refer to this mass as the Wondalga granite mass. Although it is separated from the Ellerslie granite by the "basic belt" (Vallance, 1953*b*) the two rocks are so similar that they are believed to be of roughly the same age and to have had the same petrogenetic background. A small mass, named the Belmore mass (after the Parish of Belmore), occurs between Tarcutta and Westbrook. It is composed of rocks of the Ellerslie type but has not been studied in detail.

Lithologically similar granitic rocks occur near Tumut Pond, whilst there are many interesting analogies with the gneissic granites of the Kosciusko plateau, with the Murrumbidgee batholith rocks north of Cooma, and with certain granites in central-western New South Wales.

Aplites and Pegmatites.

Fine- to medium-grained aplites and acid granites occur as dykes and veins in these granites. They are quite abundant near Adelong; elsewhere they may be more dispersed.

Sometimes acid veins are given off into the country rocks. In the basic rocks, especially, such veins may be ptygmatically folded. The acid dyke rocks are more resistant to erosion than is the host granite. Some of the dykes show post-consolidation crushing.

Mineralogically, the acid rocks consist of quartz, K-felspar, and some acid oligoclase, with small amounts of muscovite, biotite, chlorite, and pyrite. The quartz is often strained and occurs both as irregular grains (0·5 to 1 mm. across) or as aggregates of tiny grains arranged in interstitial patches or in bands around the larger grains (e.g. felspar) in the rocks. There is a slight, but not a general, tendency for the quartz to be intergrown graphically with felspar. Felspar is often altered to sericite or kaolin. The K-felspar is commonly microperthitic, the intergrown albite being of the patch- or stringer-type. The plagioclase grains may be zoned; signs of fracturing and later healing are not uncommon. Muscovite, excluding sericite, is not common, whilst the little biotite present is often partly or wholly altered to chlorite. In a few cases the dark mica is merely recrystallized to finer aggregates of itself. Pyrite occurs in these rocks near Adelong.

Coarser-grained pegmatites also occur in the granites. The K-felspar of these is often microperthitic and some of the dykes have graphic margins with quartz-rich central zones. Tourmaline crystals about two inches long may be present. Compared with the aplites these rocks are not very abundant. There seems to be little or no mineralization associated with them and, in places, they have escaped the crushing which affected the granites and aplites.

Granite-Granodiorite.

As in the first-group rocks, a complete gradation exists here between granite and granodiorite; local, more basic, phases occur and will be mentioned later. The rocks are fairly even, medium-grained types, although sometimes small felspar phenocrysts appear. Normally the rocks are greyish but near Peel's Creek school (three miles west of Batlow) a reddish phase occurs. The gneissic foliation in the Ellerslie and Wondalga masses is generally arranged north-west–south-east; dips are usually steep. In places the granites have been crushed to cleaved, crumbly material along bands traversing the masses. Crushed granites are extensive along Adelong Creek near Wondalga.

Whether they be gneissic or almost massive, the rocks have a fairly uniform mineral association, consisting of quartz, plagioclase, K-felspar, and biotite together with some muscovite and accessories (see mode in Table 4). Hornblende occurs near the contact with the basic rocks.

The quartz may have a faintly bluish colour and usually forms irregular grains with sutured margins against felspar. Strain features are to be seen even in the quartz of the fairly massive rocks. In some of the foliated granites the quartz grains may be recrystallized to aggregates of smaller granules. These granules are at times arranged in bands strung out along the foliation; such bands may be wrapped around felspar crystals which, although sometimes fractured, are never granulated in the same way as the quartz. The feature suggests that the quartz has undergone plastic flow and recrystallization. Such bands and lenses of quartz stand out on the weathered surfaces. Watt (1899) recorded similar quartz in the "granite" at Wyalong, an area which has many analogies with Adelong. Watt believed this quartz deformation to be a post-consolidation effect and it seems difficult to explain it in another way. Vermicular quartz in myrmekitic intergrowths hardly ever occurs in these rocks (cf. p. 201).

Subhedral to euhedral crystals of plagioclase (oligoclase-andesine, up to Ab_{70}) are common, often exceeding K-felspar in abundance. Albite, carlsbad, and pericline twin-laws are represented. Zoning is common and the more calcic cores are typically more altered than the margins. The felspar may be somewhat strained and, if fractured, is often healed by later felspar or granular quartz. Both untwinned and twinned (microclinic) types of K-felspar may appear as ragged grains, sometimes moulded onto plagioclase. Microperthitic intergrowths are common. With a decrease in K-felspar content the rocks grade towards quartz-mica diorites.

The chief mica is a strongly pleochroic biotite (X = pale yellow- or greenish-brown, Y = very dark brown, Z = very dark brown, almost black; 2V very small; $\beta = 1{\cdot}648$). More rarely the biotites are of the reddish-brown type. Inclusions with pleochroic haloes are commoner in the latter variety. In some rocks the biotite is clotted and recrystallized to aggregates of smaller flakes. The mica may wrap round felspar crystals in the rocks with abundant granular quartz (p. 208); the biotite here often projects across the grain boundaries into the felspar. Epidote and sphene are often associated with biotite.

Fine sericite as an alteration product is more extensive than primary muscovite. Bright green chlorite often occurs after biotite but, in addition, well-formed, pleochroic (pale yellow to bright green) chlorite flakes with anomalous blue or purple interference colours exist independently of the biotite. Apatite, sphene, zircon, calcite, epidote, and iron-ore are accessories. The sphene may be reddish-brown, feebly pleochroic, and optically positive with a small 2V. Allanite, a rare accessory, is represented by one zoned, pleochroic brown crystal found in the granite at Gadara (east of Adelong but still of the Wondalga type). Allanite also occurs in the Murrumbidgee batholith.

TABLE 4.

Mode of Specimen of Ellerslie Granite.

Quartz	16·8
Orthoclase	22·1
Plagioclase	39·1
Biotite	21·4
Hornblende	nil
Muscovite	0·3
Accessories	0·3

Granodiorite. Por. 62, Par. of Wallace, Co. Wynyard. (For analysis, see Table 5, no. 1.)

Chemical Data.

Only one representative of this plutonic group has been analysed (see Table 5) so little can be said about the chemistry of this group. For comparison, however, a compilation of analyses of more or less similar rocks from analogous environments has been made. All of these rocks are regarded by Dr. W. R. Browne (see David, 1950) as being related to his Bowning orogeny.

These analyses have been plotted on Or.Cor:Ab:An.Fem and ACF diagrams (Text-figs. 3 and 4) which are placed, for comparative purposes, below the corresponding diagrams for the first-group rocks. The more calcic members of the first group fall near many of the types included here with the second group. If the rocks plotted on Text-figure 3 do, in fact, belong to one plutonic series they show little variation in Ab over a considerable range of Or.Cor. The most basic member (from Wyalong) probably owes its present composition to reaction with basic igneous material; similar hybrid rocks are formed here along the contacts between the "basic belt" and the Ellerslie and Wondalga granites. These basified rocks are in marked contrast to the biotitic inclusion (Text-fig. 1, point no. 12) which would be roughly equivalent to the most basified phase of the first-group granites.

Marginal Features of the Second-Group Granites.

Brief mention has already been made of the fact that the Ellerslie and Wondalga granites come into contact with a variety of country rocks.

On its western side the Ellerslie granite abuts high-grade metasediments some of which are migmatitic. Remarkably shallow (25°–30°) westerly dips occur in Turner's Creek near the granite but these rapidly steepen away from the granite. To the north-west in Mt. Pleasant Creek the granite has a clear-cut contact against migmatites and does not appear to have been responsible for the veining. The granite is fairly massive here and shows no important grain size or compositional changes near the contact. Some of the contact rocks show gentle folds sympathetic with the granite margin;

these may be related to plastic flow associated with the relatively active period of the granite's invasion. The independence of the high-grade rocks and the Ellerslie granite is emphasized to the north-east where the same granite comes into contact with knotted schists or even lower-grade pelites without knots. Such rocks, together with isogradal sandier metasediments, outcrop in Nacka Nacka Creek along the northern part of the Ellerslie mass. Further east and along its eastern margin the granite occurs alongside the "basic belt". The increase in metamorphic grade to the south-east along this belt has already been described (Vallance, 1953*b*). On the eastern side of this belt, the Wondalga granite appears. Tongues of granite and acid granite, ranging from large prolongations down to veinlets, are given off into the basic rocks. Ptygmatic folds in some of these veins may indicate a certain plasticity in the host rocks during injection (Wilson, 1952).

TABLE 5.

	A	B	C	1	D	E	F	G	H
SiO_2	58·93	63·35	67·64	67·67	68·92	69·55	70·31	74·99	76·08
Al_2O_3	17·48	16·92	15·66	16·02	16·21	14·16	18·68	10·44	12·93
Fe_2O_3	1·73	1·23	1·12	0·56	0·57	0·60	0·63	5·58	0·70
FeO	5·01	4·58	3·31	3·79	2·42	3·33	1·83	n.d.	0·90
MgO	4·33	3·03	1·55	2·20	1·04	1·45	1·10	0·09	0·53
CaO	7·08	4·45	2·14	2·12	2·31	2·20	2·22	0·50	0·52
Na_2O	2·91	1·90	3·03	2·86	2·43	3·14	1·37	2·66	2·31
K_2O	1·34	2·28	3·58	3·41	4·36	4·09	3·32	4·82	5·26
H_2O+	0·73	0 86	0·90	0·57	0·93	0·30	0·65	0·52	0·33
H_2O-	0·13	0·09	0·30	0·18	0·08	0·20	0·09	0·17	0·19
TiO_2	0·52	0·84	0·62	0·71	0·52	0·54	0·35	tr.	0·35
P_2O_5	0·14	tr.	0·13	—	0·30	0·12	0·06	—	0·12
MnO	tr.	—	0·12	0·03	0·03	0·23	—	tr.	0·06
Etc.	tr.	—	0·20	—	0·04	0·22	—	—	—
	100·33	99·53	100·30	100·12	100·16	100·13	100·61	99·77	100·28

A. Quartz-mica diorite. Klondyke Mine, Wyalong. *Geol. Surv. N.S.W., Min. Res.* no. 5, 1899 : 14.

B. Quartz-mica diorite (hornblende-free). Cooma area. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 68, 1943 : 171.

C. Granite. Hillgrove area. Anal. J. C. H. Mingaye. *Rec. Geol. Surv. N.S.W.*, 8, 1907 : 217.

1. Granodiorite. Creek bed, Por. 62, Par. of Wallace, Co. Wynyard. Anal. T. G. Vallance.

D. Granite. Koetong mass (north-east Victoria). Anal. C. M. Tattam. *Bull. Geol. Surv. Vict.*, 52, 1929 : 38.

E. Granite. Hillgrove township. Anal. W. A. Greig. *Rec. Geol. Surv. N.S.W.*, 8, 1907 : 215.

F. Coarse biotite-granite. A phase of the "Blue gneiss"-Murrumbidgee batholith. Shannon's Flat, W.N.W. of Cooma. Anal. G. A. Joplin. Unpublished analysis by courtesy of the analyst.

G. White gneiss. Bunyan. Anal. G. A. Joplin. PROC. LINN. SOC. N.S.W., 68, 1943 : 172.

H. Granite. Wyangala Dam, Lachlan River, 19 miles south of Woodstock. Anal. W. A. Greig. *Dept. Mines N.S.W., Ann. Rept. for* 1932: 96.

Local reaction is typical of the contact between the granites and basic rocks. As far as the granite is concerned, the most obvious result is a basification with the development of hornblende. In extreme cases hornblende completely displaces biotite as the chief melanocratic mineral; the resultant rocks tend to become dioritic in composition. The basic rocks become somewhat recrystallized and large amphiboles may be developed. Felspar also increases in these rocks near the contact and probably contributes to their mechanical breakdown. Biotite, too, may appear in the acidified basic rocks. The whole process appears to be one of hybridization, involving reciprocal reaction between the two parents. Some splendid examples of the results of this process are to be seen in the quarry near the swimming pool at Batlow, where granite veins invade the amphibolite. Plate xii, E, illustrates one of the reaction rocks carrying a good deal more hornblende than biotite. The amphibole of these rocks is variable in colour, grey, greenish, and brownish-green types being common; as a rule the strongly greenish type mantles the others. All the amphiboles are negative and have Z^c greater than 20° (up to 28°). Some of the large hornblende grains enclose rounded felspars or have sutured margins against felspar. Occasionally these big amphiboles are rifted apart along the cleavages and granular quartz fills the resulting wedge-shaped cavities. Felspars, too, may be cracked and healed. Some of the larger felspars have granular quartz and ferromagnesian minerals wrapped round them. A complete gradation exists from granite through basified granite and acidified amphibolite to normal amphibolite. In many cases, however, the modified "granitic" veins may be readily distinguished from the essentially basic host material.

The Ellerslie granite comes into contact with the Green Hills granite along a front extending from near Batlow to Yaven Creek. Sharp junctions have not been found and the usual occurrence is a gradation over a couple of hundred yards between the two types. Each granite shows signs of foliation roughly parallel to the direction of the contact in the vicinity of the contact but, away from it, it resumes its normal parallelism to the strike of the country rocks. Directional structures are more obvious in the Green Hills mass along this contact than elsewhere within that mass.

The gradational rocks are variable even in hand specimen, but they commonly display a roughly gneissic appearance. They are frequently biotite-rich and have an uneven yet medium grain size. As both granites are broadly comparable in mineralogy no marked mineral change is to be expected in the gradational rocks. Felspar, biotite, and quartz remain the chief constituents. Andesine (about Ab_{65}) occurs as euhedral or subhedral grains up to 5 mm. across. These grains are twinned and may be zoned; they are often fractured and healed by later felspar (note the patchy appearance of the felspar in Plate xii, F). The felspars are roughly oriented in the plane of the foliation and may have biotite wrapped round them. A little K-felspar has been found and, rarely, myrmekitic intergrowths; the latter are typical of the Green Hills granite but not of the Ellerslie granite. The abundant mica is a strongly pleochroic red-brown biotite, often concentrated in clots. Muscovite is not common. Quartz is usually much strained and cracked but may not be as extensively granulated as some of the quartz in the Ellerslie mass itself. The evidence of fractured and healed felspar suggests dynamic action at some stage before the final consolidation of these rocks.

Similar gradational contacts have been found between the analogous granite-types in the area north of Cooma.

The Problem of the Ages of the Granites.

The relative ages of the two granite groups appear to be the same here as in the Cooma area where the Cooma gneiss ante-dates the Murrumbidgee batholith rocks. The second-group Ellerslie granite, along its north-western margin, cuts across high-grade rocks and metamorphic zones which are related to the Green Hills and Wantabadgery granites. It seems reasonable to believe, therefore, that the Ellerslie granite is younger than these first-group rocks. The Ellerslie granite is more extensively crushed than the first-group types, but this feature may have resulted merely from the greater resistance of the latter. Little information on relative ages is obtainable from the gradational contact between the Green Hills and Ellerslie granites. That the gradation was due to reaction related to the advent of the Ellerslie granite before the Green Hills mass was quite cold and consolidated is considered unlikely because the former obviously post-dates the metamorphism (and its thermal environment) with which the latter was closely associated. There may not, however, have been a very great time-interval between the emplacement of the two granites. Perhaps a stress environment existing during the introduction of the Ellerslie granite weakened the Green Hills type along its margins and thus facilitated reaction with the later granitic material. The local foliation parallel to the contact in the Green Hills mass may be related to this postulated stress environment.

As the Wantabadgery and Green Hills granites bear roughly the same relations to the metamorphic zones it is assumed that they are not greatly different in age.

The general similarity of the so-called second-group masses suggests that they, too, may be fairly closely related in time.

Of the absolute ages of the granite we know nothing definite. Harper (1916) believed that the granite at Adelong (second-group type) was Carboniferous and claimed that it could be traced for 25 miles to the south-east, where it intruded fossiliferous Devonian rocks. This does not seem to have been adequately confirmed. Dr. W. R. Browne (in David, 1950) suggested that the granite between Batlow and Tumbarumba (here regarded as part of the Green Hills mass) should be "very tentatively grouped as late middle Devonian but may be Carboniferous". Edwards and Easton (1937) believed the Corryong batholith to be either post lower or post middle Devonian in age. The Cooma and Albury gneisses which are almost identical with the first-group rocks here both in appearance and environment are regarded (see Joplin, 1947) as epi-Ordovician in age. The Murrumbidgee batholith rocks, similar to the second-group types, are considered to be of epi-Silurian age (Joplin, 1943).

No fossils have been recorded from the area studied, but at two localities not far away, Moorong Trig. Station near Wagga Wagga, and Carboona Gap on the Tumbarumba-Jingellic road, upper Ordovician (Eastonian ?) graptolitic remains have been found. Both occurrences are in rocks affected by granite. The writer has not been to Moorong Trig. Station, but at Carboona the granite is lithologically identical with the Green Hills type granite. A little to the west of the black (carbonaceous) graptolitic sediments at Carboona normal pelites show metamorphic features typical of the high grade of metamorphism as described here (Vallance, 1953*a*). These Carboona rocks were placed by Joplin (1947) in her zone of sills. The granite is thus in much the same metamorphic setting as the Green Hills mass and as both occur in the same belt they are regarded as probably being related in age. If the graptolites are of Eastonian age there surely could not have been a great deal of cover if the granite were of late Ordovician and pre-Silurian age. The presence of extensive metamorphic zones suggests that the first-group granites, associated with them, belong to a fairly deep zone (cf. Joplin, 1948).

If the heat flow, conductivity of the roof rocks, and the temperature difference between the granite and the surface at the time of emplacement were known, the thickness of the cover above the granite might be obtained from the equation (Birch *et al.*, 1942)

$$dQ = K.\frac{dT}{dn}.dS$$

(where dQ is the quantity of heat conducted in unit time across an area dS; K is the conductivity; and dT/dn is the temperature gradient normal to the surface dS). These values are not available here, but a rough estimate may be obtained by substituting hypothetical data. Birch (1950), in a granitic terrain, obtained heat-flow values ranging from $1{\cdot}6 \times 10^{-6}$ to $1{\cdot}9 \times 10^{-6}$ cal/cm^2.sec; in active orogenic regions the values would conceivably be higher. Studies on sillimanite (Michel-Lévy, 1950) and granitic felspars (Barth, 1951) indicate that these minerals can form at about 450–500°C. It is not unreasonable to expect that the granite would have been at about that temperature. Assuming a temperature difference of the order of 400°C., heat-flow about twice Birch's values, and a roof with the conductivity of slate, a depth-of-cover value of about 10,000 feet is obtained. Raguin (1946) quotes values of from 1500 to 3000 metres for the depth of burial of migmatites in the Pyrenees region. A cover of the order of that noted above seems to be thicker than could reasonably be expected of the Bolindian (uppermost Ordovician) rocks alone.

To overcome the depth problem it seems necessary to postulate sedimentation continuing, without break at the end of the Ordovician, into the Silurian in the metamorphic belt. Just how far into Silurian times this progressed is not known. There is no definite evidence of an orogeny at the close of the upper Ordovician in this region. The closest limit we have is to be found in the Wombat Creek area of north-eastern Victoria where sediments variously called upper Silurian or lower to middle

Devonian (David, 1950; Crohn, 1950) unconformably overlie upper Ordovician rocks. If the unconformity was related to an epi-Ordovician Benambran orogeny (David, 1950) this folding could well have occurred in lower or middle Silurian times. As it seems clear that the first-group granites were related to the metamorphism which, in a broad sense, accompanied the folding they, too, may belong to the early or middle Silurian.

At the southern end of the metamorphic belt the analogues of both granitic groups here described ante-date middle Devonian rocks (Crohn, 1950, p. 25) and perhaps the same time-relations exist here. The second-group rocks may thus post-date the middle Silurian and ante-date the middle Devonian. They are perhaps to be referred to the epi-Silurian Bowning orogeny (cf. the Murrumbidgee batholith rocks—see Joplin, 1943).

Remarks on the Origin and Significance of the Granites.

The First-Group Granites.

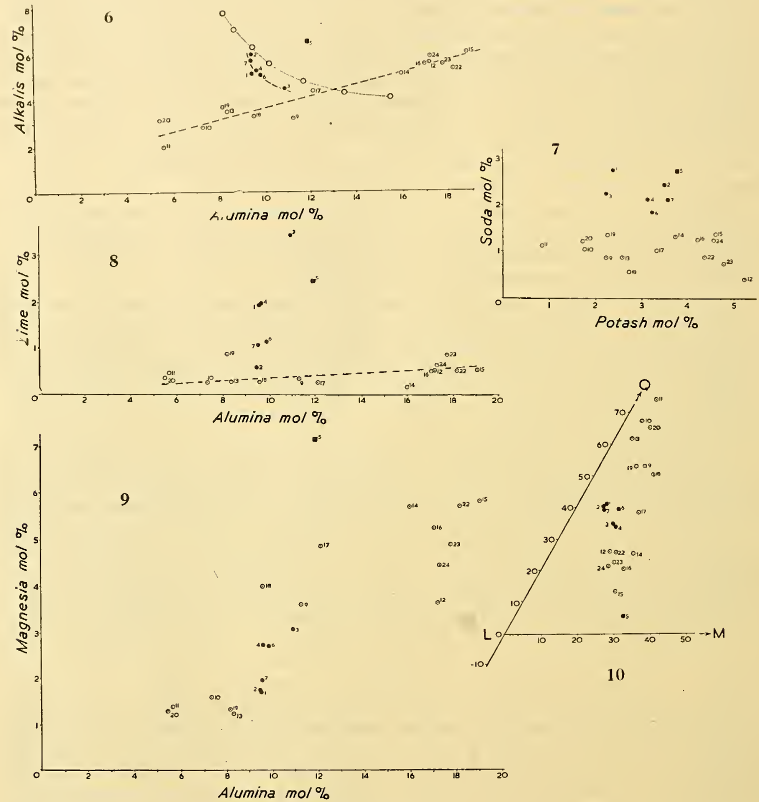
Because of the close relationship in the field between the extensive metamorphic zones and the rocks of this group the question of the genesis of the latter is of considerable interest. Like the same question asked of so many other granitic masses, however, it has as yet no completely satisfying answer.

It seems reasonable to believe that pre-granitic basic rocks may have occurred in this region, but whether or not they were related genetically to the granites has not been established (at Cooma, Joplin (1942) suggested that the chlorite amphibolite, for example, was related to the Cooma gneiss). The absence of plutonic rocks of intermediate type (apart from purely local biotite-rich patches) associated with the first-group granites rather suggests that the latter were not immediately derived from basic magma by differentiation.

If we compare the compositions of the granitic rocks and the metasediments we find several interesting points. Of the metasediments, the psammopelites come nearest to the granites in composition (cf. Text-fig. 1). Psammopelites predominate among the metasediments and the approximate proportions, obtained from a section near Alfred Town, pelites (20%), psammopelites (60%), and psammites (20%), are roughly representative of the metasediments as a whole. An average rock calculated on this proportional basis would be still like a psammopelite because the excess of Al_2O_3 and K_2O of the normal pelites would be offset by the excess SiO_2 in the psammites. Compared with the plutonic types such a rock would be deficient in alkalis (particularly Na_2O) and CaO, whilst having rather more Al_2O_3 and ferromagnesian constituents than the granites. The actual differences are, however, not very great; addition of soda alone to the metasediments would give a composition not unlike a granite. Formation of granitic rocks from sediments by metamorphic-metasomatic processes (often involving addition of soda) is nowadays a commonly invoked petrogenetic scheme. We must enquire whether there is any evidence of its action here. If metasomatism were applicable on a regional scale one would expect progressive changes in composition to accompany changes in grade in the metasediments. That such changes may take place in some cases has been elegantly established by Lapadu-Hargues (1945). Using mole percentages of various constituents he demonstrated several interesting progressions in rocks ranging from slates to granites.

The granitic rocks from this area as well as metasediments have been plotted on mole percentage variation diagrams (Text-figs. 6, 7, 8, and 9). In the alkali/alumina diagram it is clear that the metasediments, irrespective of metamorphic grade (they range up to spotted granulites and mottled gneisses), roughly fall along a straight line. The granitic rocks form a series running in opposition to the sedimentary variation. The granite curve, if extended, would meet the other curve in the region of the psammopelites. Lapadu-Hargues' curve is parallel to the granite curve. Somewhat similar features are also exhibited in the soda/potash (Text-fig. 7), lime/alumina (Text-fig. 8), and magnesia/alumina (Text-fig. 9) diagrams. The variation pattern for iron is similar to that for magnesia. Although the arrangement is rather irregular in the soda/potash diagram the plutonic rocks all have high Na_2O relative to the metasediments.

These results suggest that the present compositions of the metasediments are, in the main, directly related to their original compositions and that there has been little *apport chimique*. Actually, there may be a slight tendency for the highest-grade rocks



Text-figures 6–10.

Point no. 1, This paper, Table 2, no. 2. 2, This paper, Table 2, no. 1. 3, This paper, Table 2, no. 3. 4, This paper, Table 2, no. 4. 5, This paper, Table 2, no. 5. 6, Joplin, 1942, Table 8, no. I. 7, Tattam, 1929, Table III, no. 19. 9, Vallance, 1953*a*, Table 1, no. 1. 10, Vallance, 1953*a*, Table 1, no. 5. 11, Vallance, 1953*a*, Table 1, no. 6. 12, Vallance, 1953*a*, Table 3, no. 1. 13, Vallance, 1953*a*, Table 1, no. 4. 14, Vallance, 1953*a*, Table 2, no. 1. 15, Vallance, 1953*a*, Table 6, no. 1. 16, Vallance, 1953*a*, Table 6, no. 2. 17, Vallance, 1953*a*, Table 6, no. 5. 18, Vallance, 1953*a*, Table 6, no. 6. 19, Vallance, 1953*a*, Table 6, no. 8. 20, Vallance, 1953*a*, Table 6, no. 9. 22, Joplin, 1942, Table 7, no. I. 23, Joplin, 1942, Table 7, no. IV. 24, Joplin, 1942, Table 7, no. V.

The dotted circles represent metasediments and the black circles granitic rocks. The dotted curve in Text-fig. 6 is from Lapadu-Hargues (1945).

to have alkali/alumina and soda/potash ratios a little higher than those of the low-grade types. The increase is never great and is certainly not on the scale of Lapadu-Hargues' variation. The inclusions in the granites show more advanced stages in this series than do the marginal country rocks (see p. 205). Joplin (1942, p. 181) concluded that there was a small addition of soda in the formation of the highest-grade rocks at Cooma. Detrital albite in some of the lower-grade rocks introduces an element of doubt when assessing the amount of Na_2O added to the higher-grade metasediments. The increase in K_2O content due to the muscovitization in certain high-grade rocks near the granites is a further complication.

The evidence available in the present case suggests to me that, if the granites were derived from the metasediments, then the critical granitization stages are not clearly represented in the variation curves. This may be because actual granitization took place at deeper levels not yet exposed. There certainly seems to be more reason to believe that the granites of the Green Hills and Wantabadgery masses were introduced into their present position than that they were formed *in situ*. The small amount of *apport chimique* even in the high-grade rocks suggests a break in the granitization series. The differences in the metamorphic environments associated with the Wantabadgery granite (mainly knotted schists, localized high-grade rocks) and the Green Hills granite (extensive high-grade zone) suggest that the lithologically identical granites did not form in their present positions. Displacement seems to have been of some importance in the emplacement of the Wantabadgery granite; the deflection of the strike of the country rocks in the Oura-Wantabadgery district (see p. 198) may have been due to displacement. The plagioclase twins represented in the granites of this group include Gorai's (1950, 1951) C-twins (see p. 200). Gorai believes that granitic rocks with plagioclase in which his C-twins are important (his I-granites) are of igneous origin, having passed through a mobile stage.

From the abundance of metasediment inclusions in the granites it seems clear that a good deal of sedimentary material has been added to them even if the granites were not largely derived from the metasediments at a lower level. Whether the granites were formed by extensive contamination of a magma or by extensive granitization (anatexis essentially) of the metasediments, the final products would tend to be similar and to approach the bulk composition of the sediments. Joplin (1948) believes that both processes were active in the similar environments at Cooma and Albury. Oligoclase granite magma, derived from the base of the Sial is regarded as an active agent and Dr. Joplin considers that orthoclase-bearing gneisses are formed as a first-stage granitization of the metasediments, ahead of the advancing granite; ultimately a potash-enriched syntectic granite is produced. At Cooma and Albury representatives of the oligoclase granite and syntectic granite are found. In this area some aplitic dyke rocks have compositions similar to the oligoclase granite type (see p. 201), the main varieties in the first-group plutonic masses are akin to Joplin's syntectic or contaminated granites. The postulated primary oligoclase granite magma would be a convenient source of soda required in the making-over of the sedimentary material.

An important control in determining the metamorphic and plutonic history of this metamorphic belt must have been the miogeosyncline in which the sediments were deposited. Sinking of the geosynclinal belt must have led to folding of the sediments and, as the action progressed, the rocks doubtless acquired cleavage and schistosity. Associated with the sinking was a relative rise in the geothermal surfaces with a great increase in thermal activity at the base of the geosyncline. The thermal activity might have been related to the sinking of the geosyncline, to igneous activity at its base, or to a combination of both. Although the initial thermal gradient may have been rather steep, it is suggested that a primary thermal zoning was established in the geosynclinal sediments (cf. Kennedy, 1948). The deepest and highest-grade zone was in the region of greatest activity where, according to Joplin's (1948, 1952) theory, oligoclase-granite magma was able to react extensively with the metasediments. Looked at from the sediments' angle, an important feature of this zone was probably the addition of soda. Above this postulated granitization zone was the highest-grade zone at present visible (characterized by spotted granulites, etc.). With the steep thermal gradient this zone was probably overlain by more restricted knotted schist and biotite zones. At Cooma we may have exposed a deeper level than that represented by the high-grade zone in this area. The extensive migmatites in what is known as the injection zone at Cooma have only restricted equivalents here. Although it has been assumed that these Cooma rocks are arterites (due to magmatic injection) it may be that they are in part venitic. Locally produced (contact) migmatites at higher levels are probably more arteritic than are those of a granitization zone proper. The explanation given at Cooma (Joplin, 1943) that on low-grade metamorphic rocks a later contact thermal metamorphism was imposed is only roughly followed here in the idea of an advancing thermal front as the metamorphism progressed. The complete metamorphic series demonstrated (Vallance, 1953*a*) in these rocks stresses the essential unity of the whole process.

The suggested primary thermal zoning was probably modified when the granitic material produced in the deeper levels was rendered capable of movement and was able to escape upwards in the "thermal envelope". Although it is believed that the Green Hills granite is not in its place of origin, it may not have travelled far and still had sufficient energy available to migmatize locally the metasediments amongst which it came to rest. Such a granite might be called parautochthonous (Read, 1951). The high-grade zone rocks present evidence of a stage-wise metamorphism with signs of a thermal "peak" superimposed on somewhat less metamorphosed rocks. The Wantabadgery granite was able to escape further from the postulated granitization zone and its final roof must have been above the level of the high-grade zone and within the knotted schist zone. With the initial steep thermal gradient the knotted schist and biotite zones may have been narrower than they are now; their limits were perhaps extended by the thermal "front" associated with the intruding granite. Locally, along its margins, the Wantabadgery granite effected migmatization on a small scale. Tourmalinization of the contact rocks was also related to the presence of granitic material (see Vallance, 1953*a*).

The variations in the state of the country rocks near these identical granites have led to the latter being regarded not as the cause of the metamorphism (i.e., that the metamorphism is not purely a contact effect due to the presence of the granites), but that both metamorphism and granites were related to the same ultimate causes, bound up with the history of the geosyncline. At the levels we now see, the results of this action were mainly metamorphic but the more intense conditions of the deeper zones were probably conducive to extensive metasomatic reaction and granitization. The granites, whether broadly syntectic or anatectic, belong to the deeper level and it is only as a result of their mobility that they are now visible. The granites were, however, probably able to exert some contact thermal influence on the rocks which they invaded. Variations in the width of the knotted schist zone and, to a less extent, the biotite zone near the Wantabadgery granite may be partly related to differences in the slope of the granite contacts.

The lack of strong foliation in many of these first-group granites suggests that no very great stress influence was involved during their crystallization. That a stress environment of a rather weaker nature did exist, however, is indicated by the rough orientation of some inclusions and schlieren, and by the fact that with the Wantabadgery granite, at least, the thermal effect was not sufficiently great to overcome the schistosity of the metasediments. Schistose contact rocks are, of course, quite well known (Grout, 1933). The first-group granites probably came to rest soon after a tectonic maximum; they are in this sense late synkinematic. The Wantabadgery and Green Hills masses show features characteristic of Browne's (1931) synchronous batholiths.

That plutonic activity has occurred in a miogeosynclinal environment is itself quite interesting, though not exceptional; Marshall Kay (1951) mentions several examples of this association. Compared with the eugeosynclines there is, however, a general lack of plutonic activity in miogeosynclinal regions. The sediments of this miogeosyncline are characterized by appreciable potash and, in general, fairly low lime contents. It is probable that such features do not typify all similar geosynclines, but there is reason to expect that they are more characteristic of miogeosynclinal than of eugeosynclinal sediments. In Part I of these Studies (Vallance, 1953*a*, Text-fig. 2) the restricted chemical composition of the pelites of this metamorphic belt relative to pelites from other parts of the world, and presumably from various geosynclinal environments, was clearly demonstrated. The potassic granites of the type found in this area and which probably derived a good deal of their source material from the metasediments could only be the "most universal" (Joplin, 1948, p. 38) where there is an overall sedimentary uniformity of the type found here.

The Second-Group Granites.

These rocks have not received as much attention as the other types because they lack the close relations to the general metamorphism shown by the first-group granites. It seems clear that the second-group rocks were emplaced later than those already discussed, but how much later it is not possible to say. They may have followed fairly soon after the earlier group but it is possible that some of the rocks of the "basic belt" (Vallance, 1953*b*) were intruded during the time between the emplacement of the first- and second-group granites. In any case, the latter definitely post-date the metamorphism. Field evidence suggests that the Ellerslie granite invaded to a higher level in the crust than did the neighbouring Green Hills granite (the latter still has roof remnants, the former is quite unroofed). According to Joplin (1948) the second-group granite equivalent at Cooma also belongs to a higher level than the Cooma gneiss. The Murrumbidgee batholith does not display typical synchronous batholith features nor yet those characteristic of a subsequent batholith (Browne, 1931); Joplin (1948) refers to it as a quasi-synchronous batholith.

The lack of extensive metamorphic-metasomatic features at the margins of such large bodies as the Ellerslie and Wondalga masses surely suggests that, in general, the granites were not very active when they crystallized and that they were not formed in place. They seem to be hardly in the right setting for wholesale granitization *in situ*. The most outstanding marginal effect of these granites is their reaction on a local scale with the basic rocks (p. 210). Joplin (1948) has drawn attention to the evidence of reaction between the Murrumbidgee batholith rocks and amphibolite inclusions in the area north of Cooma. The theory was advanced that the reaction is a reciprocal effect and this is contrasted with basic inclusions being recrystallized without much reaction in the Cooma gneiss. Dr. Joplin believed that strong compression prevented reaction in the latter case but that, as the Murrumbidgee batholith was "emplaced during waning compression", hybridization was possible there and was, in fact, of considerable importance. Whether this theory be true or not there is nevertheless a marked contrast between the attitudes of members of the two granite groups in the present area to basic inclusions (and basic country rocks). Joplin considered that hybridization of the primary oligoclase-granite magma by reaction with the pre-existing basic rocks was responsible for the more basic phases of the Murrumbidgee batholith. Hybridization has occurred locally with the Ellerslie and Wondalga granites and the "basic belt" rocks, but as the hornblendic phases are largely confined to the contacts it is difficult to say how important this reaction has been in determining the nature of the second-group rocks. At Cooma, the White gneiss (Joplin, 1943) is regarded as representing the relatively "pure" (i.e. unhybridized) oligoclase-granite-magma type; a similar rock has not been found in this area unless it occur among the types classed as aplites, none of which have been analysed. In the case of the second-group granites there are few instances of much reaction with metasediments although inclusions of such rocks occur in the granites.

The second-group granites often display gneissic features indicative of a stress influence. The fact that non-gneissic acid pegmatite veins may be associated with the gneissic granite suggests stress waning before complete consolidation. Many crush-bands, however, bear witness to post-consolidation shearing. Parts of the Ellerslie mass are relatively massive, indicating, no doubt, that directed pressure was not exerted uniformly through the mass. If the granites of this group were associated with a separate epi-Silurian orogeny (see p. 213) there are not many signs of its effect on the earlier-metamorphosed rocks. This later folding must have closely followed the trends of the earlier folding if the gneissic foliation in the second-group granites is any indicator of the contemporary stress pattern. However, although the granites often have a distinct foliation, this is no real reason for postulating an intense folding associated with them.

If these granites were derived from primary oligoclase-granite magma by reaction with the country rocks this must have largely taken place at a lower level. In view of the chemical similarity between certain first- and second-group granitic rocks (cf. Text-figs. 1-4) it is possible that the earlier granites may have contributed to the development of the second-group types. A renewal of activity in the deeper levels may have resulted in this contribution not being a purely passive one based on assimilation of solid granite by a later, active magma. A certain "rejuvenation" of the earlier granitic material may have been one phase in the development of the later type. The dominance of biotite in many of the second-group granites, for example, might be related to the contribution of the earlier plutonic types and/or to deep-level granitization of sedimentary material. It is clear, however, that any postulated renewal of deep-level activity was unable to affect greatly the metamorphic picture, related to the earlier activity, which we can trace at the present level of exposure. The distinctly calcic phases of the second-group granites are perhaps most reasonably to be connected with addition of hornblendic rocks. The association and hybridization of similar gneissic granites with analogous basic rocks at Cooma, Adelong, Wyalong, and Hillgrove, amongst other places, are probably of more than casual significance in determining the nature of the gneissic granites.

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EXPLANATION OF PLATE XII.

A.—Granitized metasediment relic in the Wantabadgery granite showing myrmekitic intergrowths and traces of biotite-quartz symplektite (near centre). Crossed nicols. × 45.

B.—Pelitic inclusion in the Wantabadgery granite showing sillimanite needles and euhedral crystals developed at the expense of biotite. Ordinary light. × 13.

C.—Ultrabasic inclusion in the Wantabadgery granite showing blades and aggregates of amphibole surrounding ragged hypersthene grains (higher relief). The dark granules are green spinel. Ordinary light. × 13.

D.—Dynamically-altered Wantabadgery granite. From top right to bottom left there is a gradation from crushed granite with ruptured quartz and felspar grains to completely rolled-out quartz-mica-chlorite aggregates. Note the development of schistosity and the disappearance of large quartz-grains with increase in intensity of dynamic action. Ordinary light. × 13.

E.—Basified second-group granite from Batlow. Note the development of hornblende with a definite reduction in the biotite content. The reaction occurs where the granite comes into contact with the basic rocks. Ordinary light. × 13.

F.—Granite-granite hybrid rock from the zone between the Ellerslie and Green Hills masses. Note the irregularities in the felspar grain, and the strained appearance of the quartz. A small biotite-clot can be seen at the top (right). Crossed nicols. × 13.

All photomicrographs by Mr. G. E. McInnes.

THE OCCURRENCE OF VARVED CLAYS IN THE KOSCIUSKO DISTRICT, N.S.W.

By T. G. Vallance, Linnean Macleay Fellow in Geology.

Plate xiii; one Text-figure.)

[Read 30th September, 1953.]

Synopsis.

Varved clays occurring in the valley of Trapyard Creek in the Kosciusko district are described. The clays were deposited in a small, short-lived lake formed behind a moraine bar deposited by the Trapyard glacier during the Pleistocene glaciation. These sediments are remarkable for their content of unaltered minerals, particularly micas, derived from the local granite country rocks. The banded clays represent the first Pleistocene varved glacial deposits found on the mainland of Australia and are probably the most recent yet discovered in the Commonwealth.

Introduction and General Remarks.

The discovery of banded clays in the floor of the Trapyard Creek Valley was made in January, 1951, by Dr. W. R. Browne and Mr. D. G. Moye (chief geologist, S.M.H.E.A.) during a natural history survey of the Kosciusko region by a party of which the author was a member. Further exposures were found during the next summer.

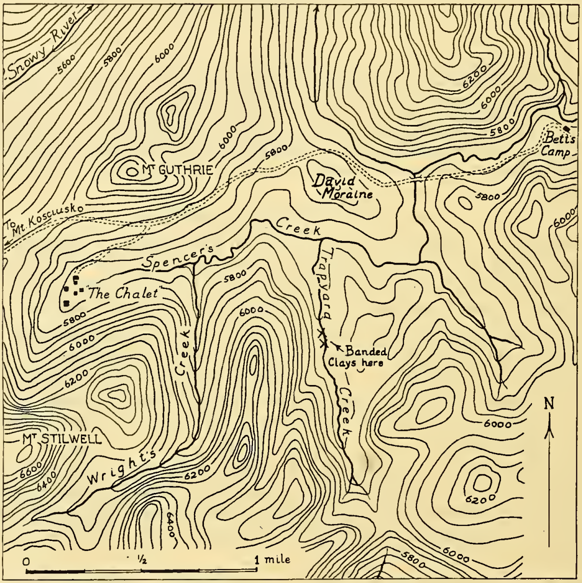
The waters of Trapyard Creek flow through a straight, open U-shaped valley about one mile long to join Spencer's Creek at a point about one mile east of the Chalet at Charlotte's Pass (see Text-fig. 1). The combined stream passes round the eastern end of the David moraine (Taylor, Browne and Jardine, 1925), a great mound partially blocking the glacial valley system, and flows down the Lower Spencer's Creek valley to meet the Snowy River.

The literature on the glacial features at Kosciusko is, as yet, not extensive, although the district shares with Tasmania the only definite evidence of Pleistocene glaciation so far found in the Commonwealth. The most recent account of glaciological studies at Kosciusko is given by Browne (1952) in which passing mention is made of the varved clays.

Differential movement due to what is known as the Kosciusko Uplift at the end of Pliocene times caused the elevation of much of eastern Australia. The effect was particularly marked in the Kosciusko district, where the highest country in Australia (Mt. Kosciusko, 7316 feet) bears witness to this uplift. It is probable that this area was essentially an isolated uplifted plateau at the beginning of Pleistocene times, a feature characteristic of it at the present day. During part of Pleistocene times glacial conditions prevailed at Kosciusko and these have left their mark on the physiography of the region. From the physiographic record Dr. W. R. Browne (1952) has pieced together a sequence of three stages during the glaciation.

During the earliest stage Dr. Browne believes that much of the area down to at least 4800 feet was covered by an ice-sheet or ice-cap of variable thickness in which there was movement of ice for the most part in an easterly direction from the vicinity of the Main Divide. Occasionally erratics which indicate such movement have been found but, because most of the region is occupied by granite, such evidence is somewhat rare. Dr. H. Rutledge and the present writer tend to regard the early-stage glacial features as related to an extensive névé-field environment rather than to an ice-cap, but all workers are agreed on the widespread effect of the earliest glaciation. The extensive ground moraine deposited over the area is largely related to this phase.

Following this stage, and separated from it by an unknown time-interval, came a period in which valley glaciers flourished. These valley glaciers in certain cases must have followed the trends of the pre-glacial streams which survived the first phase. The glaciers deepened existing open valleys and in many ways modified the landscape already smoothed by the earlier glaciation. Some of the valley glaciers headed in steep-walled cirque-hollows whilst others, like the Trapyard Creek glacier, headed in low cols (called ice-divides by Dr. W. R. Browne) with the ice supply augmented by hanging tributary glaciers. Evidence of the work of the valley glaciers is clear in the U-shaped profiles of the valleys today and in the moraine material left by the ice as it retreated to the heads of the valleys.



Text-fig. 1.—Map of the Upper Spencer's Creek basin area showing Trapyard Creek and the banded clay locality.

During the third stage the ice was much more restricted in extent and its erosive action was largely confined to cirque-cutting. This final glacial stage modified the heads of the "valley-glacial" valleys in the higher parts of the region but otherwise did not greatly affect the previously-glaciated landscape.

Trapyard Creek valley, in which the banded clays have been found, remains as a relic of the second phase of the glaciation. Towards the end of this stage, as the ice retreated up the valleys of Spencer's Creek and its tributaries (including Trapyard Creek), moraine barriers were deposited across them. The great mass of the David moraine is the largest of these recessional moraines; smaller examples occur at intervals further up the valleys. Water ponded by the moraine barriers formed small lakes which, following the breaching of the moraines, were drained and now appear as flat, boggy areas through which the modern streams meander. Lines of erratic blocks may now indicate the former moraine bars from which the finer material has been washed. Lake Süssmilch (David, 1908) came into existence immediately behind the David moraine and apparently extended across the junction of the Trapyard Creek and Spencer's Creek valleys. In the Upper Spencer's Creek valley above Lake Süssmilch recessional moraines were responsible for the damming of Lake Mackie and Lake Lendenfeld (David, 1908). Traces of clays have been found in these lake-floors but, in general, the fine material is mixed with gritty granite detritus which constitutes the greatest proportion of the material underlying the peaty bogs on the old lake floors. Above Lake Süssmilch in the Trapyard Creek valley a small lake was apparently formed behind a now much-dissected moraine bar and it was upon the floor of this that the banded clays here discussed were laid down. The absence of a distinct clay horizon in many of the test holes sunk by the S.M.H.E.A. in the Trapyard Creek valley indicates that the lake was quite restricted in extent.

The Clays.

The clays are best seen in sections where the meandering Trapyard Creek has cut down through the sediments in the floor of the valley. They are apparently not extensive and only two important exposures, about 100 yards apart, have thus far been discovered. Typically the clays are associated with decomposed granite and gritty granite-rubble derived from the country rocks by mechanical breakdown. Such granite detritus occurs both above and below the clay band in the exposures examined. Occasionally small erratic blocks may be encountered in the creek banks. As a rule the clays are confined to a single horizon although locally it may be divided by discontinuous, narrow gritty bands. Where the floor upon which the clays were deposited was irregular, small-scale slump folds are common at the base of the clay band (see Plate xiii, D). Sharply-defined fault dislocations are sometimes associated with the slump folds.

Typically the clays have an overall greyish colour but they may appear buff-coloured due to iron-staining. Alternating bands of fine and coarser (silty) material are found in many cases, though not all of the Trapyard Creek clays show this feature clearly. As a rule, in the banded clay a coarser band is broader than its finer-grained partner. Normally the total thickness of the clay deposit does not exceed 1–1½ feet. The banding of the clays suggests a seasonal deposition such as is often found in varved glacial sediments. In view of the evidence of Pleistocene glaciation in the Kosciusko region it seems natural to associate these clays with a glacial origin.

A feature of the clays is their richness in micaceous minerals and chlorite. Both biotite (green or green-brown) and muscovite occur, and these were no doubt derived, without much chemical alteration, from the granite, in the first instance by the mechanical action of the ice. The high mica content is particularly striking in thin section where it can be seen that both fine and coarser bands contain micas. In fact, the mineralogy of the bands is fairly consistent, the variation chiefly producing the characteristic banding being that of grain size. Quartz and felspar occur as well as the micas and chlorite, and crystalline kaolinite has also been noted. A few "heavy" mineral grains, including tourmaline and zircon, have also been derived from the granite. The richness in micaceous minerals has led to the development of a distinctive fabric due to the preferred orientation of many flakes in the plane of deposition. In the silt bands the larger mica flakes and quartz and felspar grains settled before the finer silt so producing graded bedding (see Plate xiii, C). Graded bedding is often also present in the fine clay bands. Kuenen and Migliorini (1950) recently showed that many cases of graded bedding are due to the action of turbidity currents. Since then Kuenen (1951) has applied turbidity currents to explain the origin of glacial varves. The graded bands in the Trapyard Creek varves, however, with their depositional fabric due to micas laid parallel to the surface of deposition, do not show many signs of the action of turbidity currents. These currents would surely produce a more haphazard arrangement of the mineral grains in such sediments.

Compared with the parent granitic material there seems to be an enhanced content of mica minerals relative to quartz and felspar in these sediments. Perhaps there has been some concentration of the flaky minerals by virtue of their being more easily transported than the quartz and felspar grains of equivalent size. The exposed clay sections are all rather near to what is regarded as the remains of the old moraine dam and may be relatively remote from the point where the sediment-bearing meltwater entered the lake. Thus there may have been opportunity for some differentiation (i.e. concentration of micas relative to quartz and felspar) in the detrital material as it was transported in suspension across the small body of water. All evidence available points to a rather local origin for the material in the clays, even though there may have been some sorting before deposition; deposition so near the source would effectively prevent much chemical breakdown of the mica minerals.

The total amount of clay and silt deposited in this lake was not great. Important factors in determining this were the restricted source area and the apparently short life of the lake. Even if only the major alternating fine and coarser bands are related to seasonal variations it is clear that not much sediment was added to the lake in most years. A total of 112 pairs of bands has been counted in the best-exposed creek-section, but as many of the pairs are very narrow (the maximum thickness of the silt bands is about 6 mm.; most bands are much thinner than this, often being less than 1 mm.) they may be related to fluctuations in the environment within a single season. A period of 112 years should be regarded as no more than the maximum possible duration of the conditions under which the clays were deposited. As many of the narrow bands may be sub-seasonal the actual number of years is probably less than 112.

The increased amount of meltwater produced as a result of the gradual amelioration of the glacial conditions led to the extinction of the lake by breaching the moraine dam, thus causing the lake to be drained. Locally-derived granite sand and gravel washed down on top of the clays helped to preserve them, but the erosive effect of Trapyard Creek in cutting back to a base level has now again exposed these banded sediments.

Age of the Banded Clays.

These varved clays of the Kosciusko area obviously post-date the glaciers which carved such valleys as that of Trapyard Creek. They are most reasonably associated with the retreat of the valley glaciers and thus may ante-date the local, late cirque-cutting glaciation. By correlation with Tasmania (see David, 1950, p. 629) the clays might belong to the period following the Yolande glacial stage. (Three Pleistocene glacial stages, the Malannan (oldest), Yolande, and Margaret (youngest) stages, each separated by interglacial periods, have been recognized in Tasmania—see A. N. Lewis, 1945.) The only other recorded occurrence of Pleistocene glacial clays is in western Tasmania. The Tasmanian varves belong to the period of waning of the ice sheet related to the Malannan or first-stage glaciation. Thus the Trapyard Creek varved clays are probably the most recent so far recorded in the Commonwealth of Australia.

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